A STUDY IN LOGICAL MEMORY[1]

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INTRODUCTION

(1) *The Problem.* The chief aim of this investigation has been to see if certain of the laws established for the recall of nonsense material will hold for sense or logical material as well. The special phase of this problem which has been studied is to determine whether divided repetitions prove more effective than accumulated repetitions in learning material with meaning. The more important subordinate problems which have developed from this larger problem are: the relation of logical learning to rote learning, or memory for ideas as opposed to words; and, in particular, the effect for recall of distributed as compared with accumulated repetitions; and the influence of time (the curve of forgetting) upon the amount and character of the material retained. Although the chief interest in the problem has lain in the quantitative aspect of the process of remembering, careful introspections taken

[1] From the Psychological Laboratory of the University of Michigan.

throughout the experiments show something of the qualitative nature of the problem as well.

(2) *Literature.* Relatively little of the vast amount of literature which has been published on memory and the learning processes has a direct bearing on this problem. Only that work which deals more or less directly with the learning of logical material will be briefly reviewed.

(1) *Learning of (a) Nonsense Material and (b) Logical Material.*

(*a*) The pioneer experiments of Ebbinghaus (3) and Jost (7) in the field of memory were done almost entirely upon material without meaning. Following them have been investigators who have used both material without and material with meaning, as Radossawljewitsch, who used both in his study of forgetting. A number of experiments have been made upon logical material, but usually for verbal recall, not for the memory of ideas as opposed to words. Balaban (1) studied the difference between logical and mechanical memory, using syllables, words, and compound words.

(*b*) Henderson(6) has carried out probably the most complete research with logical material. He had 212 subjects, ranging from school children of the fifth grade to graduate students in college. A typewritten copy of a short prose selection was handed to each subject to be learned in 3 min. At the expiration of that time the subject was required to write as exact a reproduction as possible. The aim of the experiment was to determine the amount and character of the material retained. The subject was then tested two days and four weeks later.

The results of 259 complete papers were scored on the basis of the story, topics, sub-topics, details, and words. All words of the original text that were reproduced in their former contexts were scored full value. Commonplace words, articles, prepositions, and conjunctions were not scored when reproduced out of their context. On the other hand, an unusual word was regarded as remembered even though it appeared in the wrong context. Henderson found that the older students got ideas more than words, and that there was a slight tendency for more advanced students to remember better. He found also that a single reading, concentrated, was nearly as effective for immediate reproduction as 3 min. of study. Details disappeared owing to generalization and there was a tendency to substitute. The details least consonant with the thought were usually forgotten.

Whipple (18, pp. 394-403) refers to the same process of generalization. Referring to Binet and Henri, he says that they found a tendency to express ideas in their own terms, rather than those employed in the original passage. They estimate that memory for connected sentences is approximatly 25 times as good as memory for discrete terms. The general conclusion, we may say, of the investigators using logical material is that ideas are retained, not the original words and that there is a strong tendency to generalize when learning subject-matter with meaning.

(2) *Distributed as opposed to Cumulative Repetitions.*

(*a*) For nonsense material, Ebbinghaus showed the advantage of distributed repetitions in learning. Using the "Saving Method," he

found a saving of more than 30 repetitions in relearning by distributing his repetitions over 3 days. Jost,(7) likewise, found a saving in relearning with repetitions scattered. He used the "Saving" and "Treffer" methods, and found that 30 repetitions at once tested on the following day were very ineffective as compared with the 30 repetitions distributed within limits. He found an advantage in scattered repetitions in both the methods which he used; a saving in relearning, and also a greater number of successes. He concluded that the "Treffer" method was the better of the two.

Perkins'(15) experiments upon nonsense syllables showed also the greater advantage of repeitions distributed within limits. Her main problems were, first, "to discover if there was a limit to the degree of distribution that might be advantageous" and, secondly, to determine, in cases where more than one repetition was made in a single day, "if learning was easier when more than one day was allowed to intervene between the groups of readings, and to discover, if possible, the most favorable period." The results showed that the highest percentage of success was obtained by the use of one reading every third day. She found that, in general, the smaller the number of repetitions used at a sitting, the higher was the percentage of success.

(*b*) For sense material. The most recent experiments in which scattered repetitions are compared with cumulative, and which are very closely related to this problem, are those of Edwards(4). He compared the relative value of 6.5 min. as opposed to 4 plus 2.5 min. when studying a page of history. It was so arranged that the total amount of time was the same for all. Half of each class was a review group, half a non-review group. His subjects were high school and grammar grade pupils. The non-review groups studied 6.5 min. and wrote 12 min. and took an examination from 10 to 12 days later. The review groups studied 4 min., wrote for 12 min., and about 5 or 6 days later reviewed for 2.5 min. It was found that the review groups were better without exception in reproduction. The review groups could do sometimes 50 per cent more than the non-review groups per pupil.

(3) *The Curve of Forgetting of* (*a*) *Nonsense Material,* (*b*) *Logical Material.*

(*a*) In any memory problem, one phase is its relation to the "Curve of Forgetting." Although material with meaning is retained better than nonsense syllables, the same general tendencies are shown in the rate of forgetting. Working with nonsense syllables, Ebbinghaus(3) found that 42% of forgetting took place after 20 min.; 56% after 60 min.; 64% after 9 hrs.; 66% after 24 hrs.; 75% after 6 days; and 79% after 31 days. That is, forgetting took place rapidly at first, and then more slowly.

Radossawljewitsch(17) also found approximately the same results for nonsense material, *i.e.*, a decided loss at first, then a more gradual loss of the syllables that had been learned. His experiments differed from those of Ebbinghaus only in a smaller amount forgotten at first. He found a relatively slow period of forgetting between 6 and 21 days.

(*b*) Although the major portion of his work was done with nonsense syllables, note may be made of one experiment by Ebbinghaus on material with meaning. Even after 22 years, he found a retention of stanzas of poetry learned so that they could be said once, perfectly,

and not seen in the interim. Radossawljewitsch(17) also used material with meaning; a portion of Schiller's *Siege of Troy*. Two stanzas were assigned to his subjects who read them through repeatedly until they could reproduce them twice without error. He found that one-third of the material with meaning was gone in 2 days, one-half in 7 days, while material without meaning was lost much more quickly. With both nonsense and sense material, with these two investigators, the same general "Curve of Forgetting" holds, namely that at first forgetting takes place rapidly and then more gradually.

In connection with the curve of forgetting, Bean(2), in his monograph, presents results from his experiments on forgetting of relatively simple motor acts, sensations with relatively little meaning, and sensori-motor experiences. He says that his own results do not warrant altering the general character of the Ebbinghaus curve of forgetting, nor introducing any other general types of curve. But the rate of forgetting is variable, depending on (1) the degree to which the material had been learned in the first place, (2) the distribution of the repetitions, (3) the kind of material learned, (4) the method by which it is measured, and (5) individual difference in retentiveness.

II. The Method of Experiment

(1) *Subjects.* The following persons served as subjects, Prof. W. B. Pillsbury, Miss Nellie Perkins, Mr. J. Winter, and Mr. H. W. Crane, who performed memory tests during one college year for this experiment. Five other persons served as subjects for a few tests, so few that they had to be discarded. The class in Introductory Psychology furnished material for several tests. The writer served as a subject for a year and a half, and then after an interval of three and a half years continued the experiments for about six months. In the following experiments, these subjects will be designated as follows: Prof. W. B. Pillsbury, Subject I; Mr. Crane, Subject II; Mr. Winter, Subject III; Miss Perkins, Subject IV; Miss MacKay, Subject V.

(2) *Materials.* The so-called logical material was of two kinds for each subject. In each case, the subject chose or was assigned material with which he was relatively unfamiliar but in which he was interested to some extent. Subject I used Organic Chemistry and Russell's *Principles of Mathematics*. Subject II used Embryology (Piersol) and History (a detailed account of the Battle of Gettysburg). Subject III used the same Embryology, and Descriptive Geology. Subject IV used the same Embryology, and a History of South America. Subject V used Economics and a History of Scotland. Embryology was a new subject to those who used it in this experiment, and it presented difficulties in terminology as well as in meaning. The assignments in this were very short.

During the first part of the experiment, Subject V used a text book in *Money and Banking.* Experiments begun after an interval of three and a half years were made with the same text-book and the publications of the National City Bank in addition. The history used in these later experiments was the literature sent by Sir Gilbert Parker to the members of the American Bar Association, Wilson's *Division and Reunion,* Walling's *History of Socialism,* and a *History of French Literature.* In every case, the subjects used books they had never seen before.

Previous experiments in the use of sense material have been limited for the most part to sentences, short paragraphs, or two or three stanzas of poetry. In this experiment, the portions to be learned were much longer, and were always of about the same length. In mapping out the material for the other subjects, as well as for myself, I attempted to have the assignments as nearly equal in length as possible. I laid more emphasis, however, upon the logical place to end the assignment than upon having a uniform number of ideas. The assignments varied, with the exception of those in Embryology, from two pages to four or five. It may be noted, in this connection, that the length of the assignment had little effect upon comparative results.

An assignment covering several pages gives a test of logical memory in its practical aspect, since in school, in college, and in practical life, one is never limited to a mere stanza or paragraph. Such subjects as history and economics, for example, were chosen because they were the sort of subject-matter one generally reads, in addition to being logical material.

When I began working on this problem, after a three and one half year interim, it was necessary for me to use shorter assignments than those which have been described, assignments requiring perhaps 5 to 7 min. to read. This method enabled me to have many tests under way at the same time on different assignments of both history and economics.

Note may be made of one great difficulty which arose and made the number of experiments fewer than they otherwise would have been. The subject-matter for the tests was the consecutive material in a chosen text. Thus two pages, let us say, were chosen for the first assignment, the following two pages for the next assignment, the following two pages for the third, and so forth. If history, for example, had been read five times in one day and was to be tested in two weeks, no further experiments could well be performed in that subject until that test had been made. If a second experiment

had been begun on the following pages before the first had been finished, such confusion in both learning and recall would have resulted that both final results would have been invalidated. It would have been impossible to distinguish one assignment from the other when the time for testing came.

The other subject-matter, embryology, could be introduced in the interim, and experiments made in that, but even then there was a loss of time in the experiments extending over longer intervals. As is evident, this difficulty did not present itself in the short-time tests. Repetitions could be made and the subject-matter tested on the following day; and the questions could be answered two days later and the next test begun. I obviated this difficulty, of the loss of time, in my own later experiments by learning various assignments in several books in both economics and history and having several tests overlap.

(3) *Method of Learning.* The total number of repetitions used throughout the experiment was five, which number was chosen arbitrarily. One repetition consisted in reading the assignment through once very carefully. The subject read his assignments at the same time of day, in so far as was possible. He chose his own method, which was to be uniform throughout the experiment; he could read aloud or not as he wished, slowly or rapidly. After reading the assignment, the subject attempted to drop it completely out of mind. This was very difficult to do at first; since the subject knew it should be remembered, it would be recalled again and again in the effort to have all the subject-matter of the assignment available when the test was to be made. Had this method been continued, it would have introduced a great source of error; some portions might have been reviewed more than others, portions incorrectly recalled might have been gone over until they seemed a part of the context, and there might have been a constant effort to keep the material fresh in mind, particularly if the test were two weeks away. A little practice, however, enabled the subjects to dismiss the assignments completely after reading.

The subject read his assignment as directed; for example, five times in one day, once each day for five days, or three times in one day and two times the next, and wrote all he could recall without any assistance of any kind at the expiration of the stated time. Two days later (this time was also chosen arbitrarily) he answered questions which had been carefully made out, covering as nearly as possible all the ideas in the given assignment. The repetitions were scattered over varying intervals of time, from five repetitions in one day, to

one repetition every fifth day. The extreme time-limits for testing were from two hours to three, four, and six weeks, in one case, each. The majority of the tests, however, lay within the limits (including) two hours and one month. Anything interesting in the way of introspection at the time of reading or of testing was noted by the subject.

(4) *Scoring of Material.* The purpose of this investigation, as has been stated, has been to see how many ideas of any given prose assignment could be retained after certain periods of time, after five careful readings at varying intervals. The original assignment was scored very carefully. I read over the text and counted the number of ideas in this way. One half of a sheet of paper was used to score the ideas in the text, and the other half was used for the test. Usually the first and last words, with abbreviations between, of what I called an idea were written down. To give a concrete example from one of the assignments: "Only that statesman, writer, or sociologist, has the hearing of the public to-day who can bind his proposed reforms into some large far-seeing plan." This was abbreviated as follows:

Socialism

Pages 2 and 3

Text	Test
1. Only states, b. f. plan.	2.
2.	2.
3.	3.

In this way, when it came to scoring a test on the other half of the sheet, the original idea was perfectly obvious. The original assignment, in addition, was always at hand for reference in scoring the tests; for often the idea of the subject was correct, although phrased entirely differently. Just as the original text was scored, so the report of the subject was carefully gone over, the total number of ideas in each found, and the percentage of the ideas recalled in each case was calculated. No scoring was done for words or different parts of speech, the purpose being solely to find the percentage of the whole number of ideas in the original text which could be reproduced.

The scoring was done very closely, making the percentages low, particularly in tests extending over several weeks or more. This was necessary because a high degree of accuracy was obtained in an immediate test, say two or twenty-four hours, and many details were given which would have been forgotten in a longer interval.

The first question which naturally arises in regard to the method of scoring is: how were wrong or partial ideas scored? The answer is that, as a rule, either the subject-matter had been entirely forgotten or was recalled correctly. This was found to be true in general throughout the experiment, although there were a few exceptions. Wrong ideas, dates, or figures would be found occasionally, but comparatively seldom. These were simply disregarded if the idea was correctly recalled. If several partial ideas were found in one test, credit was given for a whole idea, but little scoring of partial ideas was necessary.

All figures in the following tables show the percentage of the material retained, that is, the number of correct ideas the subject retained. The first figure shows the original test, the second, the test made with the aid of the question. Thus, in subsequent discussion, 0—28, means that nothing was remembered by free recall, and 28% of the total number of ideas in the given assignment, with the aid of the questions.

III. Tabulation of Data and Introspections of Subjects

In the following pages the results of each subject will be summarized, and the introspections of interest noted, with particular reference to their bearing upon the problem of imagery or imageless thought. This experiment has shown that, while comparisons of the results of the same individual can be made, none can be made of the results of different individuals.

Table I, Subject I. (1) *Organic Chemistry.* This material required 15 or 20 min. each day to read. It proved interesting, and no pertinent introspections accompanied it. The greater value of divided repetitions is shown as compared with cumulative.

(2) *Mathematics.* These sections were long and difficult. The introspections show: "Not all understood and did not reread anywhere; general impression vague," on the first day. Second day: some mind-wandering. Third day: still rather blind; last part still hazy. Fourth day: "Felt disinclination for the work, one page not appreciated at all in the reading." Again, the introspections taken at the time of reading another assignment: "Read once, room quiet and conditions favorable, pretty well followed. Conditions favorable on following day, and seemed to understand and often to anticipate."

By reference to the table it will be seen that the assignment read two times the first day and three times the second and tested in two weeks gave 0-28 per cent. The notes taken at the time of reading show that it was not understood at the time. The introspections recorded at the time of writing the test show the dependence of recall upon some form of imagery. "At first there is nothing more in the way of recall than a picture of a large page with rather dirty type, with Sec. No. 41 rather low on the left-hand side of the page. As

I hold myself to it, I think that the subject-matter must be of 'implication,' but with no memory of what phase of it may be considered. All is accompanied by unpleasant strain sensations. Nothing more comes. I give it up for a time. Nothing more would come yesterday. Occasionally a stray word would present itself, with the feeling that something else was behind it, but nothing definite would develop, and I could not be sure that the idea came from the right passage."

Summary, Subject I. (1) *Organic Chemistry.* (*a*) Distributed repetitions proved to be more effective than those which followed one another closely, but there seemed to be little difference in value in the spacing of the repetition. That is, material read each day for five days was remembered as well as that read three times the first day and twice the second day. Also material read twice in one day and three times on the following day was recalled as well as that read on alternate days. The results are too few in number to give any definite conclusions, except that when the subject-matter is to be tested in two weeks, repetitions which are scattered are more advantageous. (*b*) The questions brought back more than free recall. (*c*) There was a decrease with time in the amount retained.

(2) *Mathematics.* There were too few results to give any conclusions.

TABLE I

SUBJECT I

Organic Chemistry			Mathematics	
Free Recall	Question Recall	Repetition	Free Recall	Question Recall
		Tested in 2 Weeks		
19.9	19.9	5 times in one day	....	....
25.8	48.6	Daily for 5 days	6.7	14.1
42	52	Alternate days for 5 days	29	40
29.1	55	3 times 1 day, twice 2nd day	24.3	45
40	65	2 times 1 day, three times 2nd day	0	28
		Tested in 10 Days		
43.9	46.1	Daily for 5 days	....	....
		Tested in 7 Days		
		Daily for 5 days	14.8	24.4
		Tested Following Day		
65	74	5 times in 1 day	....	....
72.7	83.3	Daily for 5 days	32.6	36.7

Table II, Subject II. (1) *Embryology.* These assignments were short, owing to difficulty in terminology. The approximate time for reading was from 5 to 6 min. Material read once each day for five days and tested in two weeks gave the highest percentage of any of

the two weeks' tests. One introspection may be noted, showing the subject's dependence on visualization. "I can not remember much about this material. I could not visualize; it has no meaning for me because I can not picture it, or connect it with anything in my experience."

(2) *History.* The history read once every fifth day gives a very low percentage, showing that repetitions so far apart are probably past the limit of advantageous dimension. One introspection may be quoted: "This history I did not feel nearly as sure of as I did the first. I have a general sort of hazy notion; can get but very few facts, and they seem vague and unconnected. During the learning process, I was conscious of the confusion of the details of the material with that of the first. Had I been able to go back over it, I think I should have been able to keep it straight."

The portion read five times in one day and tested on the following gave a test that was an almost exact reproduction of the text, including figures and number of troops. This was very unusual. It may be noted that even after two days, with the additional help of the questions, there was a fall of 5%.

Summary, Subject II.[2] (1) *Embryology.* The results were too few in number for any positive conclusions.

(2) *History.* (*a*) Repetitions distributed within limits (up to one repetition a day for five days) proved most effective for recall when the subject-matter was to be tested in two

TABLE II

SUBJECT II

History			Embryology	
Free Recall	Question Recall	Repetition	Free Recall	Question Recall
		Tested in 2 Weeks		
31.1	40.5	Daily for 5 days	43	75
0	43.4	.....	....	....
....	....	3 times 1 day, twice 2nd day	0	10
....	....	2 times 1 day	....	....
....	....	2 times 1 day, 3 times 2nd day	25	40
4.12	10.9	Once every 5th day	22.2	....
31.9	40	Alternate days for 5 days	15.7	27.7
		Tested in 7 Days		
47.6	54.3	Daily for 5 days	....	....
		Tested Following Day		
98.6	92.3	5 times in 1 day	....	....
70.8	72	Daily for 5 days	65.1	65.1

[2] These subjects, I and II, worked irregularly and the series is not complete. The results, however, show the tendency, confirmed by the more complete series which follow, for the scattered repetitions to have a greater value than the accumulated when the matter is recalled after the longer periods of time, while the two are of approximately the same value for recall after a single day.

weeks. (*b*) For immediate recall the accumulated repetitions proved more valuable than distributed. This, however, was in a single instance only. It shows the tendency, confirmed by the following series of other subjects, that for immediate use the value of the scattered and of the massed repetitions is about equal. (*c*) The questions brought back more than free recall. (*d*) There was a gradual decrease with time of the amount retained.

Table III, Subject III. (1) *Embryology.* The assignment read five times in one day and tested in two weeks gave the following introspection. "I can not recollect distinctly what the material was about. I studied it in succession I think, but I don't remember what it is on. I may be able to answer some of the questions when I see them." It is interesting to note, in relation to this, that the portion read once every fifth day and tested in two weeks gave almost exactly the same percentage and about the same introspection. "Have tried to think just what this section is about, but I can't place it. I have a mass of facts before my mind but I can not pick out the pertinent ones." Repetitions which come too close together or too far apart are of little value. There is utter blankness when trying to recall the subject-matter. Only when some form of imagery is possible does any of the content return.

Another introspection may be noted. "I am completely mystified as to the exact content of the paper I am supposed to reproduce to-day. Not that I do not know some of the facts, but I can not distinguish which they are. I think I shall be able to answer some of the questions without difficulty." When the questions were answered, the following comment was made. "This is a terrific paper, but I can not account for it exactly. Maybe it is due to overwork, or I was not in proper shape when I studied it."

Summary, Subject III. (1) *Embryology.* (*a*) Distributed repetitions are more effective than accumulated, without exception, in the two weeks tests. One reading a day was the most effective distribution. In the material read on alternate days, the initial test with free recall is absent, but the question recall shows the highest percentage of material retained in the two weeks series. (*b*) Repetitions too close together or too far apart are of little value. (*c*) For immediate recall, accumulated repetitions were as valuable as distributed. (*d*) The questions brought back more than free recall. (*e*) There was a decrease with time in the amount retained.

Without exception, with Subject III, distributed repetitions proved more effective for recall after intervals of seven days to two weeks.

(2) *Geology.* The tests were too few in number for a comparative summary. The two points which were shown are: (*a*) Questions brought back more than free recall; (*b*) There was a decrease with time in the amount of the material retained.

TABLE III

SUBJECT III

Geology			Embryology	
Free Recall	Question Recall	Repetition	Free Recall	Question Recall
		Tested in 2 Weeks		
33.3	22.2	Daily for 5 days	26.6	46.6
....	....	5 times in 1 day	0	16.6
13.7	35.5	Alternate days for 5 days	....	57.1
....	....	4 times 1 day, once 2nd day	0	24.2
....	....	Once every 5th day	....	16.3
....	....	3 times one day, twice 2nd day	0	25
		Tested in 10 Days		
13.8	33.3	Daily for 5 days	....	....
35.9	....		....	....
....	....	2 times 1 day, 3 times 2nd day	61.9	....
		Tested in 7 Days		
....	....	Daily for 5 days	38.4	42.1
....	....	Once 1 day, 4 times 2nd day	0	33.3
		Tested Following Day		
61.7	67.6	5 times in 1 day	47.7	63.1
....	....	Daily for 5 days	40	40
40	40	3 times 1 day, twice 2nd day	....	....
		Tested in 2 Hours		
47.2	41.7	Daily for 5 days	85.7	....
48.7	43.6		61.9	71.4
....	....		53.5	50

Table IV, Subject IV. (1) *Embryology.* As has been stated, embryology was entirely new subject-matter; the names and terminology were difficult and the sections, therefore, short. This was the same material used by Subject III. An introspection at the time of testing material read three times in one day and twice the second day is as follows. "I had a perfect picture of all of this at the time of reading. It has completely faded. This was one assignment I felt sure of, but the test shows almost a complete loss of material." After six weeks the questions were answered and 40% was retained, showing that the subject was justified in her feeling of surety.

(2) *History.* I shall quote this subject's introspections in detail, since they give clearly her method of learning and her dependence, for recall, upon a definite image. "In learning the material, I tried to visualize the whole, that is, to put it into an outline form and build up relations between the parts so that one would naturally call up what followed. I also pictured out very accurately every detail. In the recall I found that these two things helped me. It was only after I could not get a mental picture of the details that I could not remember. In recall, I found I was more or less dependent upon my outline. Just as soon as the main facts came to me, the rest fell in order. It seemed to be a continuous process without effort. In many

cases I could nearly get the facts. I could feel them on the fringe and yet they were inhibited. I could see just how they stood on the page, but just what they were I could not get. In several places there was confusion; several things came back, but I did not know their relation to each other or to the whole. I felt that if I could get the name I could fill in the detail. In a few cases whole areas were blank. I could not get a visual picture of the page or fact. The whole mass had fallen away. I knew something was gone, but just what or where I could not tell."

Summary, Subject IV. (1) *Embryology.* (*a*) Distributed repetitions proved more effective than accumulated repetitions, without exception, particularly in the two weeks tests. One repetition each day and one repetition on alternate days were most advantageous. There was little difference in the amount retained when the repetitions were divided in various ways, as three times in one day and twice the second day, or four times in one day and once the second day. Likewise, in the ten and seven day tests, daily repetitions were more valuable than those which were made all in one day or two or three a day. (*b*) For immediate recall, cumulative repetitions were as valuable as distributed. (*c*) Repetitions too far apart, as one repetition every fifth day, as well as those too close together, as five in one day, were of little value. (*d*) The questions brought back more than free recall. (*e*) There was a decrease with time in the amount retained.

(2) *History.* (*a*) Distributed and accumulated repetitions proved to be about equally valuable, for both long and short intervals. This is an exception to the rule which has seemed to hold up to this point. The embryology experiments of Subject IV showed, without exception, the advantage of distributed repetitions for recall after long intervals. One possible explanation for the equal effectiveness of accumulated repetitions in this subject-matter might be that the subject had an unusual ability in remembering historical material. She seemed to be able to reproduce it no matter how it had been read. (*b*) For immediate testing, scattered and massed repetitions were of equal value. (*c*) The questions brought back more than free recall. (*d*) There was a decrease with time in the amount retained.

One review test may be noted, in passing, by Subjects III and IV. They were given on February 26th material they had read the latter part of October and the first of November, and on which they had been tested at that time. The conditions of the review experiment were that they were to reread the original text and test in two hours. The four assignments which were retested in this way showed that, after

several months, the subject-matter first learned with repetitions distributed within the limits of one repetition every fifth day showed a higher percentage of material retained.

TABLE IV

SUBJECT IV

History			Embryology	
Free Recall	Question Recall	Repetition	Free Recall	Question Recall
		Tested in 2 Weeks		
23	42.3	5 times in 1 day	0	27.7
32.5	46.3	Daily for 5 days	7.1	64
45.3	49.4	Daily for 5 days	60	66
23.2	61.3	Alternate days for 5 days	43.4	52.3
33.3	69.8	3 times 1 day, twice 2nd	25	40
16.2	50	Twice 1 day, 3 times 2nd	0	5
....	....	Once every 5th day	0	30
....	....	4 times 1 day, once 2nd day	24.2	24.2
		Tested in 10 Days		
52.6	59.4	Daily for 5 days	36.8	88.4
34.3	62.5	Twice 1 day, 3 times 2nd	19	14.5
		Tested in 7 Days		
59	49	Daily for 5 days	52.5	84.2
54	25.5	Daily for 5 days	52.3	66.6
54	25.5	Daily for 5 days	52.3	66.6
....	....	5 times in 1 day	28.5	45.6
		Tested Following Day		
56.9	62.8	5 times in 1 day	61.1	88.8
82.6	64.2	Daily for 5 days	20	16
52.8	64.3	3 times 1 day, twice 2nd	....	....
		Tested in 2 Hours		
63.4	65.3	Daily for 5 days	78.5	78.5

Table V, Subject V. My own experiments fall into two well-defined groups. The first group consists of tests made in fourteen, ten, seven, four, and two days, and two hours, with the five repetitions divided differently, as three times one day, two times the next, or four times one day and once the following day, etc.

The results of the other subjects, as well as my own, seemed to show the advantage of divided repetitions over longer periods of time. Believing this point to be worthy of further investigation, I undertook the second portion of this experiment. A series of 60 tests was planned. This series was made up of 10 tests of five times in one day, and 10 tests every day for five days, tested the following day, in two weeks, and one month. I made up the questions for myself many weeks, often several months, before I was ready to use the material. I made the sections to be read shorter and, as has been said, I used various books and pamphlets on economics, thereby making it possible

to have many tests under way at the same time. In this way the second series of the 60 tests was carried on more systematically and with less loss of time than the first series.

First Series of the Writer's Experiments

(1) *Economics.* In my introspections I find that, almost without exception, I laid stress upon the necessity of visualization for recall. At first this was more or less unconscious. I did not realize my dependence upon it. One of the comments upon an economics assignment was: "I can visualize where what I don't know is. It is over the page, all of that page, and the top of the next, but I can not get it."

Comment may be made in passing upon one test of material read every day for five days and tested in ten, which gave only 12% in the initial recall. When I made this test, I was ill with tonsilitis. Any state of imperfect physical or mental health or fatigue greatly influences the amount recalled of material which has been learned, and explains departures from the general rule. In this connection there is this introspection; "I simply can't get it at all. This assignment was read five times in succession late at night after a busy day. I know where my last assignment stopped. I am curious to see the questions, for I feel I know some of the material if I could only start, but I have no visualization of any portion of it. I remember exactly where on the page the last assignment stopped, and something of its content, but what follows is an absolute blank." It is interesting to note that the above-mentioned last assignment had been read on five successive days and tested in two weeks. Thus, after several weeks, it was retained better than the later assignment read five times in one day and tested in four.

(2) *History.* The introspections written at the time of reading or of testing the history assignments show the same dependence on visualization for recall. One comment was: "I have lost all visualization here; that is, the continuity is gone, and these isolated facts have returned without any logical connection."

There was one three-weeks test in this group, which gave 3.8% with free recall and later 44% with the questions. The note accompanying the first test was: "I think if I could only start, I could remember it." Evidently this was true, as the questions two days later showed.

After four weeks, material read three times in one day and two times the following day gave very low percentages. Compared with history read in the same way and tested in two weeks, giving 14.6%—25.3% as compared with 9.3%—12.8% in this test, there was but relatively little difference. Little was lost between two weeks and one month.

Several other introspections may be noted which are general in their nature, and summarize in a way the introspections of this portion of the experiment. "After the assignment was read, it was dropped completely out of mind. So completely that often there would be no idea of what the subject-matter was about when the time came to test the material read, for instance, two weeks before. Then, by long continued thinking, the place where the assignment began came into consciousness, that is, on what part of the page. Next, the ideas in the text came, very often many of the same words if the test was an immediate one, but by no means verbatim if the

interval had been a long one since the last reading. When the continuity was lost (and this continuity seemed strangely dependent upon the visualization of the subject-matter), that is, when the logical connection was gone, everything seemed to slip away. Isolated facts might come up, but without their connection. There is nothing quite comparable to the feeling of utter blankness, and of strain as well, in attempting to recall an assignment after a long period of time for which the repetitions had been cumulative. There is present a realiza- that some of the subject-matter is retained, but what, it is impossible to tell, for it was not forcibly enough imprinted to be revived."

Summary of the Writer's First Series of Experiments

The full series of experiments in both economics and history shows the same general tendency throughout. The following summary will, therefore, be based upon the results of the work done in both subjects. For both economics and history, we may say that:

(1) Distributed repetitions proved more valuable than accumulated repetitions for recall, particularly after seven, ten, and fourteen days. One repetition each day and one on alternate days were the most effective. (2) Accumulated repetitions were as effective as scattered for immediate recall. There was no great difference in the amount recalled when the repetitions were divided differently. (3) The questions brought back more than free recall. (4) There was a decrease with time in the amount retained.

TABLE V

SUBJECT V, FIRST SERIES

History			Economics	
Free Recall	Question Recall	Repetition	Free Recall	Question Recall
		Tested in 2 Weeks		
36.5	36.5	Alternate days for 5 repetitions.....	22.2	33.3
14.6	25.3	3 times 1 day, twice 2nd.....	11.7	33.3
0	28.8	Twice 1 day, 3 times 2nd.....	17.4	30
		Tested in 10 Days		
44.8	49	Daily for 5 days.....	12.3	38.4
42.5	....	Daily for 5 days.....	....	....
18	38	3 times 1 day, twice 2nd.....	20	28.5
....	....	3 times 1 day, twice 2nd.....	0	32.4
....	....	Once 1st day, 4 times 2nd.....	28.5	46.4
25	33	5 times in 1 day.....	24.2	36.3

TABLE V—Continued

SUBJECT V, FIRST SERIES

History			Economics	
Free Recall	Question Recall	Repetition	Free Recall	Question Recall
		Tested in 7 Days		
46.8	59.3	Daily for 5 days	54	25.5
....	....	Daily for 5 days	36.1	44.9
5.7	30.7	Once 1st day, 4 times 2nd	32.2	41.9
34.6	38.4	3 times 1 day, twice 2nd	30.4	30.4
35.6	43.8	5 times in 1 day	20	33
		Tested in 4 Days		
46	52	5 times in 1 day	0	21.6
43.3	52.8	Daily for 5 days	47.3	47.3
51.8	62.5	3 times 1 day, twice 2nd	25.6	42.8
48.2	54.2	Once 1st day, 4 times 2nd	39.5	55.8
58.8	64.7	Once 1st day, 4 times 2nd	....	....
21	40	Twice 1 day, 3 times 2nd	38.4	53.8
		Tested Following Day		
52.8	65.5	3 times 1 day, twice 2nd	67.5	52.5
....	....	3 times 1 day, twice 2nd	40	46.6
47.1	54.5	Once 1st day, four times 2nd	52.5	56
52.1	52.1	Once 1st day, four times 2nd	....	....
....	....	Daily for 3 days, 1 day omitted and 2 succeeding days	41.9	54.4
....	....	Every alternate day for 5 repetitions, 2 days between last 2 readings	46.1	46.1
54	56	4 times 1 day, once 2nd		
58.1	66.6	Alternate days for 5 repetitions	47.5	55
....	....	Alternate days for 5 repetitions	52.9	52.9
58.8	68.8	Twice 1st, twice 2nd, once 3rd	....	....
		Tested in 2 Hours		
76.7	76.7	5 times in 1 day	67.7	67.7
70.3	79.2	Daily for 5 days	56.9	54.9
64.5	56.1	3 times 1 day, twice 2nd	65.7	60
		Tested in 3 Weeks		
3.8	44.2	Twice 1 day, 3 times 2nd	....	....
		Tested in 4 Weeks		
9.3	12.8	3 times 1 day, twice 2nd	....	....

Second Series of the Writer's Experiments

The particular noteworthy point which had been developed thus far was the greater value of distributed repetitions in learning, when the subject-matter was to be tested after a long interval. The following experiments were performed in an attempt to develop this hypothesis into a theory. A series

of ten experiments each, of five repetitions in one day and five repetitions, one each day, tested on the following day, in two weeks, and one month was performed, making a total of 60 tests (or 120 in all, including the answers to the questions).

The results show a marked degree of consistency. All the figures which I shall use to compare one series with another will be averages of each series of ten experiments. For example, 11.49%—22.41% means that the average amount recalled for the ten tests, five in history and five in economics, for free recall was 11.49%, and with the aid of the questions, 22.41%.

(1) The first comparison of averages in this series will be that of material read five times in one day, and of material read each day for five days, both tested in one month.

Read	Tested	Average (10 tests)	Mean Variation
5 times in 1 day	1 month	11.49—22.41	4.8 — 6.48
Daily for 5 days	1 month	30.59—41.66	9.41—10.84

That is, almost three times as much was recalled after the end of a month, when the repetitions were divided. Almost twice as much was recalled with the aid of the questions when the repetitions were divided.

(2) The second comparison is as follows. The time of testing in this case was two weeks after the last reading.

Read	Tested	Average (10 tests)	Mean Variation
5 times in one day	2 weeks	13.13—30.2	10.21—10.57
Daily for 5 days	2 weeks	37.26—49.09	11.24—11.95

The relation is much the same as in the tests of one month; almost three times as much was retained when the repetitions were scattered. There is not so much difference in the amount retained with the questions as in the preceding case, although appreciably more was recalled with the questions when the repetitions had been scattered.

(3) The third comparison of this series is of the averages of subject matter tested the day after reading.

Read	Tested	Average (10 tests)	Mean Variation
5 times in 1 day	Next day	66 —69.5	10.62— 8.87
Daily for 5 days	Next day	64.4—70.6	10.57—10.19

For immediate recall, cumulative repetitions proved as effective as distributed. All of the subjects in this experiment have shown the same result, indicating the tendency for accumulated repetitions to be as effective as those which are scattered. There are always many factors which might influence a single test, and make variable the amount retained. This series is significant in that it represents averages, and therefore confirms the point that repetitions which follow one another closely are as valuable as those which are distributed, if material is to be utilized at once.

The introspections of this series have the same tenor as those of the former series and of the other subjects of the experiment. I shall quote only a few. Of the history assignments tested in one month we find: "I can see where the assignment is on the page even to the paragraphs; I know that if I can ever start, some facts will come back to me. I have no idea as to the words the author used; everything is general. I know just where a long succession of facts in the text is; if I only had the right cue to set me off, I am sure I could reproduce some of them. But it is all exasperatingly faint." I quote this because it is typical of many of the introspections written at the time of testing assignments read a month before. Again, "I have entirely lost all the wording of this; the sentences were rather long as I recall them, and only a few of the main ideas come, clothed in my own words."

Another comment was: "I have a general idea of the whole, but the several Russian names throughout the portion confused me. While learning it, I remember thinking, 'Now if I can't recall those names, I won't recall any of it, and I am afraid I can't recall them.'" It seems to have worked out so.

A general observation of the material read five times in one day and tested in one month is: "Invariably there is a decided vagueness, and if anything is recalled it is only in the most general terms. I have a visual picture of the whole assignment, and although I can see where it begins and ends, I have but little idea of the content."

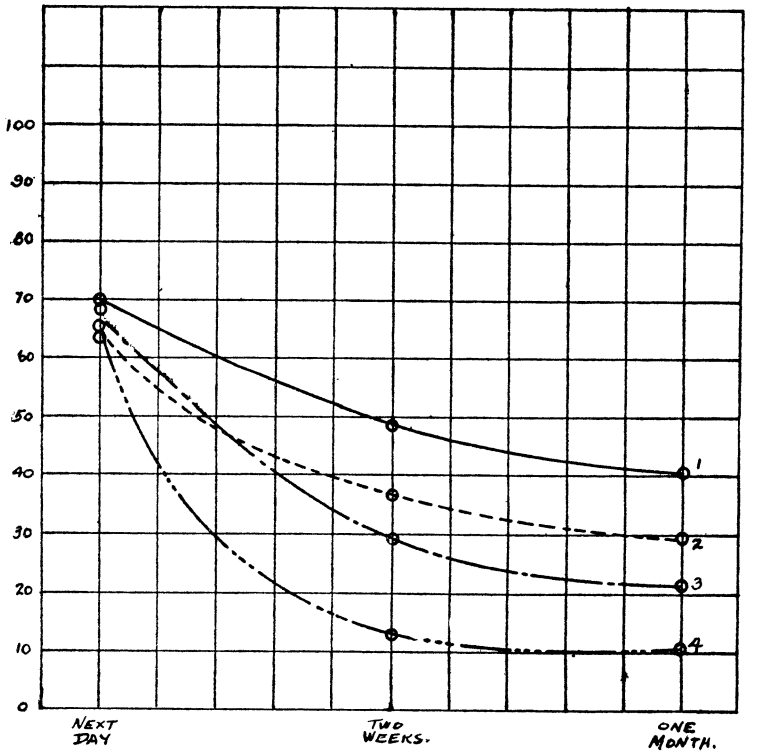
Similarly, of a test five times in one day and tested in two weeks, we find: "I can see this whole paragraph but I know absolutely nothing in it." Again, "I know that this assignment began on the right-hand side of the page about the middle, but I simply cannot recall anything." Very careful and full introspections were taken, but it is sufficient to quote these which I have chosen as typical of them all.

I do not know how I knew what the general idea was when I could not recall it. It is significant that I had to have, first of all, the visual picture of the appearance of the page for any recall; then came the feeling that I knew something of the subject-matter in the text. Yet I could not bridge the gap between my concrete image of the printed page, which I had once known, and the general idea of its content.

The Curve of Forgetting

The writer's second series of experiments contains data sufficient to show the influence of time upon the amount of material retained.

CURVE I.



LEGEND

1. MATERIAL READ EVERY DAY FOR FIVE DAYS QUESTION RECALL ——————
2. MATERIAL READ EVERY DAY FOR FIVE DAYS FREE RECALL - - - - - - - - - - - -
3. MATERIAL READ FIVE TIMES IN ONE DAY QUESTION RECALL. —— • —— • ——
4. MATERIAL READ FIVE TIMES IN ONE DAY FREE RECALL —— ··· —— ··· ——

SUBJECT MATTER READ FIVE TIMES IN ONE DAY

Tested	Free Recall	Question Recall
Following day.....	66 % retained	69. 5% retained
In 2 weeks.....	13. 3% "	30.12% "
In 1 month.....	11.49% "	22.41% "

SUBJECT MATTER READ FIVE TIMES IN ONE DAY

Tested	Free Recall	Question Recall
Following day.....	64.41% retained	70.59% retained
In 2 weeks.....	37.26% "	49.69% "
In 1 month.....	30 % "	41.66% "

The accompanying curve shows this result graphically. It conforms with the work done on the Curve of Forgetting. Forgetting occurred rapidly at first, and then relatively little was forgotten in the period from two weeks to one month. Forgetting occurred much more rapidly when the material had been learned with the repetitions massed, for the first two weeks, but after that the loss was slight. There was a much greater drop in the curve when the repetitions were accumulated. No matter in what way the material was learned, the loss in the first two weeks was very rapid. It is for retention after longer intervals that the value of divided repetitions is particularly noticeable. We may say, then, that for these experiments, Ebbinghaus' Curve of Forgetting applies to sense as well as to nonsense material.

Class Experiments.—The writer made some experiments on a class in Introductory Psychology. The results of four written lessons show the same general tendency we have found throughout; namely, that, for immediate recall, readings following one another closely are as effective as readings which are scattered. The method used was this. The instructor assigned a certain number of pages in the text-book in Elementary Psychology. He asked one half of the class, in preparation for their twenty minute written lesson, to read the assignment three times in succession, the other half to read it on three alternate days. One hundred eighty-five papers written by students who conformed to the instructions were obtained, despite the failure of some of the students to follow directions accurately.

The ideas in the text were scored as has been described, and the average number of ideas that could be reproduced for each group was found.

TABLE V

SUBJECT V, SECOND SERIES

History			Economics	
Free Recall	Question Recall	Repetition	Free Recall	Question Recall
		Tested in 1 Month		
10.5	26.3	5 times in 1 day	18.7	31.2
0	15	5 times in 1 day	0	16.6
10.5	15.7	5 times in 1 day	11.7	23.5
13.6	27.2	5 times in 1 day	9	27.2
21	31.5	5 times in 1 day	9.9	9.9
Average for free recall for both subjects 11.49, M. V. 4.8				
Average for question recall for both subjects 22.41, M. V. 6.48				
40.9	45.4	Daily for 5 days	41.1	58.8
18.7	31.2	Daily for 5 days	26.6	33.3
26.3	31.5	Daily for 5 days	20	33
22.2	38.8	Daily for 5 days	22.7	31.8
31.2	37.5	Daily for 5 days	56.2	75
Average for free recall for both subjects, 30.59, M. V. 9.41.				
Average for question recall for both subjects, 41.66, M. V. 10.84.				
		Tested in 2 Weeks		
9	32.7	5 times in 1 day	0	20.5
0	20	5 times in 1 day	0	7.1
31.5	42.1	5 times in 1 day	24.4	44.4
22.2	33.3	5 times in 1 day	26.6	40
0	20	5 times in 1 day	17.6	41.1
Average for free recall for both subjects, 13.13, M. V. 10.29.				
Average for question recall for both subjects, 30.22, M. V. 10.57.				
20	32.5	Daily for 5 days	40	50
47.3	63.1	Daily for 5 days	64.7	64.7
40	66.6	Daily for 5 days	50	61.1
25	33.3	Daily for 5 days	17.6	23.5
34.7	52.1	Daily for 5 days	33.3	50
Average for free recall for both subjects, 37.26, M. V. 11.24.				
Average for question recall for both subjects, 49.69, M. V. 11.95.				
		Tested Following Day		
55.7	55.7	5 times in 1 day	54.6	62.5
58.4	66	5 times in 1 day	51.3	51.3
90	85	5 times in 1 day	76.4	76.4
73.9	73.9	5 times in 1 day	60	73.3
72.2	83.3	5 times in 1 day	67.7	67.7
Average for free recall for both subjects, 66, M. V. 10.62.				
Average for question recall for both subjects, 69.5, M. V. 8.87.				
53.3	66.6	Daily for 5 days	49.3	49.3
49	63.4	Daily for 5 days	77.7	83.3
70.5	76.4	Daily for 5 days	61.9	66.6
62.5	62.5	Daily for 5 days	94.4	100
57.1	64.2	Daily for 5 days	68.4	73.6
Average for free recall for both subjects, 64.4, M. V. 10.57.				
Average for question recall for both subjects, 70.6, M. V. 10.19.				

"A" is material read three times in succession.
"B" is material read on three alternate days.

The table showing the results from these tests is as follows:

Quiz	No. of Papers	How Read	Average % Retained
I	17	A	34
	15	B	46
II	25	A	45.7
	24	B	45.6
III	34	A	49
	19	B	52.4
IV	32	A	40.2
	19	B	39.3

These results conform with the general tendency which has been shown in the experiments of the subjects tested at length, namely, that readings which are distributed and readings which are accumulated are equally effective for immediate recall.

Brief General Summary of the Results of All the Subjects of the Experiment

(1) Distributed repetitions were more valuable than those which were accumulated when the subject-matter was to be tested in two weeks or one month.

The experiments of Subject I in Organic Chemistry and Subject II in History, though few in number, followed this rule, and, without exception, the Embryology tests of Subject III. (The Geology experiments of Subject III were too few in number to be significant.) The full series of Embryology experiments of Subject IV followed the same law. An exception is to be found in the History experiments of Subject IV, in which accumulated and distributed repetitions were of equal value. The single experiments in the first series of Subject V showed the advantage of scattered repetitions, yet not so strikingly as the second series. In the latter, without any exception, distributed repetitions proved to be very much more valuable, for periods of two weeks and one month. Since the final percentages of this series are based upon averages, not single experiments, we may attach much more importance to them.

(2) For immediate recall (recall after two or twenty-four hours) accumulated repetitions were as valuable as distributed.

This was found to be true throughout the experiments for all subjects and for the tests made upon the class in Elementary Psychology.

(3) Repetitions too far apart were as ineffective as those which came too closely together. Although there were relatively few of the tests with repetitions distributed to one every fifth day, the results which were obtained showed that repetitions so far apart were almost valueless.

(4) The questions always brought back more than free recall.

(5) There was a decrease with time in the amount retained.

(6) For all subjects, there was a dependence for recall upon visualization of the text.

IV. Discussion of Results and Summary

(1) *Discussion of Results*

(*a*) *Sources of Error.* The sources of error which form an important factor in such an experiment as this should first be noted. Most important of all, perhaps, is the "personal equation," the individual variation in each subject from day to day, in general health, fatigue, mood, interest and lack of interest. This is an element which cannot be controlled experimentally. A passing mood, or a state of fatigue at the time of learning or of testing, will entirely alter the usual result.

Another source of error which cannot be controlled is the lack of perfect uniformity in the difficulty of the material to be learned. The same books and pamphlets were used throughout the experiment, but as in all subject-matter some pages were easier than others. They had to be taken in succession, otherwise the logical connection would have been lost. Thus if a few pages happened to be easier to remember and the repetitions to be distributed advantageously, an unusually high per cent was retained. This lack of absolute uniformity in the subject-matter was a constant factor, and can only be eliminated by averaging a number of results.

It may be said that knowing the time the test was to be made might introduce a source of error. Whether it was to be made in two hours or in two weeks might, unconsciously, influence the amount of effort expended in learning. Under ideal conditions of experiment, the subject would not know when he was to be tested. Practically, however, it was necessary to map out the work in advance, and the subject was given explicit directions when to read and when to test, for a short series of experiments at a time. In my own later experiments, when I had several tests overlapping, I paid but very little attention, if any, to the time of testing, while I was reading the assignment.

Another criticism, and perhaps a just one, is that I scored the text, test, and made out the questions on my own material. This may appear to have given me an unfair advantage in having seen the subject-matter before beginning to learn it. I do not think, however, that this was the case. The questions on the subject-matter were made out for other subjects as well as for myself, often months before they were to be used. As a rule, I did not even recognize the material when I read it.

Again, I scored all material myself; it was not rechecked by anyone else. I made two checks to see if this criticism was valid, and to see if my method of scoring was consistent. First, I scored again some tests of my first series which had been made a year or more before, and secured practically the same percentages. Secondly, when I began my experiments again, after an interval of over three years, during which time the problem was not touched, not even thought of, I compared the results with those obtained before the work was interrupted, and found a general uniformity. These two checks seem to indicate that the criticism has no vital significance.

(b) Statement of Results and Their Practical Application

One of the points to be considered first in a discussion of the results is this. All the subjects without exception, some to a far greater degree than others, were dependent upon visualization of the subject-matter for reproduction. There was in no case recall of the logical sense of the subject-matter without some imagery. This is in harmony with Finkenbinder's (5) investigations. He found with 18 subjects using problems of various kinds and of varying degrees of difficulty, as mathematical problems, mechanical puzzles and the like, that the visual image was the first definite figure to appear in 95% of the recalls. In this connection Offner(13) says (in relation to reproduction) that we have the factor of the appearance of the text, having a certain association of words in a spatial scheme.

Since visualization was essential for any reproduction, the results of my experiments agree with those of the investigators who hold that there must be some imaginal factor for recall, as opposed to those observers who hold that imagery is not essential. We can only conjecture as to the dependence upon imagery had some of the subjects for this experiment been of a non-visual type, as the acoustic-motor type, for example.

It is interesting to note, as has been stated before, that there were few errors in the tests which were scored. Gross

errors were seldom made. As a rule, if the ideas in the text were retained, they remained in their correct form. In the immediate tests, the author's style and his actual wording were sometimes reproduced. As the time-intervals for testing increased, however, the important ideas remained and became more generalized, the original wording of the author was lost, and more and more details dropped out. This also coincides with the general results of memory investigations in logical material, particularly with those of Henderson. We also found a tendency to generalize.

One of the most important results of this investigation is to show that for immediate recall accumulated repetitions are as valuable as divided. This harmonizes with general observations. It is a common experience for us to learn something for immediate use; say, to be utilized in a few hours or on the following day. School children learn for immediate reproduction; the more quickly the content is reproduced the more nearly accurate it is. Offner(13) asks: "May the greater value of accumulated repetitions for recall be attributed to our habits of learning, or are our habits of learning due to this?"

Accumulated repetitions make material available for immediate use: in common parlance this is really "cramming." An example in a superlative degree is the actor's cramming or "winging" of a part. "A part taken in the morning can be done perfectly at night; every scene was read before going on, the shape of the part was mechanically fixed in memory, that is, the position of each speech on the paper. Words would be acquired but not always the sense, for there would be no time to think about the context . . . . One result of these hurried studies was, words would not remain, fading from the memory as rapidly as acquired."[3]

The same principles apply in a lesser degree to "cramming for examinations." Lessons which were not learned at the time they were assigned can be so intensively studied that, for 12 or 24 hours, the greater part of the work of the semester can be retained. It is a common observation that anything so learned vanishes almost immediately.

The facts in practice, then, are that for immediate use a great mass of material can be made available by intensive review or "cramming," a short time before it is to be utilized. tical life, carried on as accurately as possible, showed exactly Our experiments upon subject-matter such as is used in practhe same conditions to be true. We may conclude, therefore,

[3] H. F. Osborn, Rapid Memorizing, *Psych. Rev.*, ix., 1902, 183 f.

that subject-matter which is studied very intensively a short time before it is to be used, both in practical life and in scientific investigation, is soon lost, and very little if any of it can be recalled after a lapse of time.

The second important result of this research is the fact that accumulated repetitions, which are highly effective for immediate recall, are ineffective for recall after several weeks. Our experiments show the very great advantage of divided repetitions when learning is to be tested after longer time intervals, particularly two weeks and longer, after the last reading.

While our experiments cover too few periods of time to give a complete picture or to formulate an equation, our results for all of the subjects of the experiment show that forgetting took place rapidly at first, and then much more slowly. Meumann says that whatever we know twelve or more days after learning presumably stands longer at our disposal. On the other hand, what we can reproduce at a glance or at a single reading, we have for only a short time. Similarly in our experiments, there was a rapid loss at first, while if the subject-matter were retained two weeks there was little additional loss at the end of four weeks. Our few results indicate that the curve of forgetting has the same general form for logical as for nonsense material.

The fact that divided repetitions have an advantage over accumulated has been explained in two distinct ways. The first suggestions were based on the assumption that the distributed repetitions had some advantage for learning inherent in the distribution itself, that there was less fatigue or ennui or other disturbance, when few repetitions were made at one time. A second hypothesis is that the distributed repetions offer opportunities for some favorable change in the effects of learning, some change that takes place after the learning gives the distributed repetitions an advantage. Each of these general classes offers several subordinate suggestions. The first suggestion of the first class was made by Müller, to the effect that the fatigue from many repetitions in succession would explain the more favorable results from the distributed repetitions. Under Müller's direction Jost made a series of tests in which a number of repetitions of other series were made before each of the repetitions with distributed learnings that should make the total number equal to the number given to the accumulated repetitions. This insured that the subject should be more fatigued or bored during the divided than during the accumulated repetitions. Neverthe-

less the advantage of the divided repetitions persisted. Müller seems to have accepted Jost's results as convincing evidence that his suggestion did not furnish the real explanation.

Another explanation in terms of conditions incident to the nature of the individual has been suggested recently for animals. Animals, too, learn a maze much more quickly with divided than with accumulated repetitions. In testing the phenomenon Lashley (10) confirmed the results of earlier investigators objectively, but attributed the fact to the dislike of being taken away from the food, and to general handling. This was an immediate accompaniment of reaching the food-box in accumulated repetitions, but was not so prominent in the divided repetitions. He is particularly vigorous in his preference for this as opposed to any 'setting' process in the nervous system as an explanation of the advantage for the divided repetitions. Whatever may be the status of this explanation for animal learning, there is no corresponding advantage for distributed repetitions in human learning. As Jost's experiments show, fatigue or ennui is not a sufficient explanation. One factor that might be expected to favor accumulated repetitions may be suggested. This is the evidence of making progress in the learning. As several repetitions are made at one sitting one understands, and feels in consequence a confidence in the ability to repeat, that is pleasant as a sign of progress. To be sure one does not actually know that one is learning. The only direct evidence of that is furnished by the test itself, but confidence of that ability increases with understanding. Were any detrimental influence of accumulated repetitions to exist in man, one would expect it to show itself in Jost's experiment mentioned above, in which the divided repetitions were repeated after a number of repetitions had been made of other series to induce the same state of fatigue.

The more usual explanation of the second type is in terms of the perseveration tendency. This must stand or fall with the interpretation of that term. If we assume with Müller that there is a continuance of the activity of the nervous system for some time, as long as forty-eight hours, and that during that time associations constantly increase in strength, we should have all that is essential for our purposes. In this assumption it is necessary to distinguish what might be called the immediate readiness for response from the persisting tendency to return that is connected with association. This may be made clear if we think of dispositions left in the nervous system as consisting of two parts; one, more temporary, which

gives the nerve tract affected a tendency to continue active for a relatively short time, and for this activity to become conscious whenever there is no other activity present; the other, more permanent, which serves in some way to connect that tract with another involved when the tract excited with it or immediately after it is aroused. This is the ordinary association. The former tendency dies away relatively quickly; the second persists in some degree for years and diminishes relatively slowly. Since the tracts are active in the same way during the perseveration period as during the original action, it may readily be assumed that the associative process or formation of connection between that and the tracts active during the process accompanying and immediately succeeding will be increasing in strength during the period of partial activity. If we grant this assumption, the greater effect of divided repetitions will be due to the fact that after each repetition the activity will continue for a time. With each repetition this activity will start at a maximum and will diminish to zero. When the same number of repetitions is made in immediate succession, the degree of activity of the tissues involved will not be much greater after the series than after each repetition, and its return to zero will be almost as quick as after each of the divided repetitions. What is gained for the divided repetitions as compared with the accumulated is the setting due to the perseveration for each of the groups of repetitions as compared with the single repetition.

The evidence for the existence of perseveration is, first, the general existence of a continuance of the cortical excitations as seen in the memory after-image. It is fair to assume that there is no sharp cessation of this persisting effect: the only question is how long it continues. Müller and Pilzecker, who first made use of the term perseveration, although the phenomenon had been observed by others before, cited the instances of songs that run in the head, the recurrence of vivid images of exciting positions in a game of chess, etc., which last for hours and occasionally days, as compared with the few seconds that the memory after-image has been demonstrated to continue. They also found that certain syllables shown in one experiment were likely to reappear in another experiment soon after, although there were no syllables shown, or other associations, that would suggest them. Foster, who repeated the experiments with the object of deciding whether these cases were sufficiently frequent to justify the assumption that perseveration was a factor to be reckoned with, came to the conclusion that cases of appearance of old syllables were

due to unnoticed associations, or to the fact that they were sounds likely to be made because of their ease or similarity to emotional expressions. It should be noticed that all that he claims is that they might be due to association, not that he was able to trace the associates in each case; and the ease or resemblance to emotional expressions is a matter of opinion. Foster also does not question the persistence of the nervous activity, but only the likelihood that experiences will rise to consciousness soon after their original appearance when not excited through associations. He grants all that is needed for the explanation of our facts.

The indirect evidence is also striking. I mean by indirect evidence in this connection a series of well established facts which can be readily explained if we assume persveration, but which are hard to understand if we deny it. There are three such sets of facts: first, retroactive inhibition; secondly, the rapid forgetting for the first few hours or for two days, followed by a relatively slow decline of the strength of associations, and thirdly the fact we are dealing with, the advantage of divided repetitions. We can understand retroactive inhibition and the related retrograde amnesia of pathological states if we assume that the effects of experiences are at first of relatively little value for the formation of associations that shall lead to their reinstatement, and that, with the passage of time, through the perseveration they become more firmly established. The rapid course of forgetting of meaningless or nonsense material at first might also be explained if there are two parts to the memory process, one due to a quickly disappearing tendency to return, the other to a tendency that diminishes very slowly. The rapid diminution of the likelihood of recall at first would be due to the gradual dying out of the perseveration, while the later part of the curve would represent the more gradual weakening of associative bonds. Finally, we see that the perseverative tendency makes explicable the advantage of divided repetitions. Miss Perkins' results would also give an indication of the length of time the perseveration continues to be strong enough to be detected. Her results show that divisions up to one every third day were more effective than accumulated repetitions, and our present investigation confirms that for sense material. This agrees with the form of the curve of forgetting, which loses its sharp descent at the end of the second day, according to both investigations of the subject. We find, then, an explanation of the three important general facts and of the more detailed

time relations, if we assume that retention is partly due to perseveration, partly due to association.

Closely related to this explanation is Jost's suggestion that the determining advantage of the divided repetitions is to be sought in the fact that older associations are more easily brought to full effect by new repetitions, and also that older associations are loosened less quickly than more recently formed ones even if they have the same strength. This law was established before Müller and Pilzecker formulated their doctrine of perseveration, and so takes no account of the latter. It is easy to see that perseveration constitutes an explanation of the greater persistence and more ready revivability of the older associates. If we assume the two parts or phases of the retention process, perseveration and association, the associations would increase in strength during (and because of) the perseveration process. The tests made soon after learning would give a high percentage of successes by the method of successes, because part of the recall would be due to the perseveration. They would not be so quickly learned to the full, because the association process would not have attained the strength that it would have after the perseveration period has passed, and this alone apparently is of value, or at least is of greatest value, in learning to the point where the series can be repeated without promptings.

It is interesting to note that both in these experiments and in Miss Perkins' the distributions could be greater than were advantageous. We found no effect, or very slight effect, from repetitions made one each fifth day. Miss Perkins found that repetitions one each fourth day were less effective than one each third day. This might emphasize the second part of Jost's first law, that old repetitions are more easily brought to full strength than are new of the same strength. Taken with no other implication this might mean that the testing was of little or no value unless the associative trace was refreshed by a new repetition made soon after the perseveration had ceased. This is compatible with the perseveration theory, but one must admit the fact that the effect of the immediate repetition *plus* the setting is lost unless a new repetition is made within a certain time. The time must be before all effect of the first repetition is lost, and to obtain the best effect it must come when we may assume the perseveration of the original repetition is just disappearing.

Ladd-Woodworth(9) suggest that some of the effect of the division may be due to the more rapid forgetting of errors, which serves to leave the correct responses more prominent

than they are when the repetitions are accumulated. This would explain the more rapid learning of the mechanical operations of men and animals. It would be less important in rote or logical learning of verbal or symbolic material, in which few errors are made, and where the distributed form of learning is more effective even if each repetition is perfectly accurate. There it must be subordinate to some one of the other explanations.

On the whole it seems that there must be some change in the associations that takes place after each group of repetitions which is more favorable to the divided repetitions. In the light of Jost's law this also favors all older formed associations as compared with the new formed. The most likely source of this improvement in the period after each repetition is the perseveration tendency. The associations increase in strength during the perseveration, and if a new repetition is made before its strength has waned too much the effect of the distributions is beneficial.

We also need to explain the most striking general result of this investigation, that divided repetitions are relatively more favorable after a long period than after a short, after a week or a month than after twenty-four hours. Miss Perkins states that she had some evidence to this effect in her series of nonsense syllables. If we compare her results with those obtained by Jost we find that the difference between the published results of the two is not very great. Jost tested after twenty-four hours, Miss Perkins after two weeks. If we compare his results for 3x8 (eight repetitions on each of three days) with her 2x8, and his 6x4 with her 2x4, and his 2x12 with her 2x8, we find that he has 18, 39, and 53% for one observer and 7, 31, and 55% for another as against an average for all observers for Miss Perkins of 9, 25, and 43%. If we average the results of Jost's two observers there is a slightly greater difference in favor of the more distributed repetitions after the longer period, but it is so slight as to be negligible as compared with the differences we have found for sense material. That the difference should exist does not seem open to explanation from the facts of related phenomena, although it harmonizes with the observations of daily life.

An explanation of the fact of the greater effect of distribution after a considerable period than after a short might be found in the mere average time that elapses between learning and test. For if one repeat once a day for five days and test on the day following the last repetition, the average time between learning and test would be four days as compared

with one for the accumulated repetitions. On the other hand, if the test came after two weeks, the average time elapsed would be seventeen days for the distributed as compared with fourteen by the accumulated. The advantages of the distribution might be sufficient to overcome the smaller relative advantage of the long interval and not that of the short interval. There is nothing in the experiments to indicate why the difference should be more apparent with sense than with nonsense material. And the average time between repetition and test would be present for nonsense as well as for sense material. It is evident that other factors are necessary to complete the explanation. Whatever the reason, the increased effect of perseveration or the resulting 'setting' becomes more apparent after the lapse of considerable time.

(2) *Summary*

(1) Divided repetitions, within limits, prove more effective than cumulative repetitions with logical material as well as with nonsense syllables. The greater value of distributed repetitions is particularly noticeable when material is tested two and four weeks after learning.

(2) For immediate recall, cumulative repetitions prove as effective as repetitions that are distributed.

(3) The forgetting of sense or logical material is rapid at first, then proceeds more slowly, as Ebbinghaus found for nonsense syllables.

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